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Recent Laser-Plasma Interaction Studies at LLNL

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Abstract

Recent analysis and modeling of Nova experiments which address our understanding of stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) will be presented. Forward and backward SBS levels have been investigated with SSD of varying bandwidth and with polarization smoothing using an f/8 focusing geometry to emulate NIF conditions. The interpretation of the experiments is aided using F3D, a fluid code which includes modeling of SBS and SRS; a parallel version of F3D is being developed which will allow the modeling of a plasma approaching the size of an entire NIF laser beam. Cryogenic targets have recently been employed to investigate the dependence of SRS saturation levels on ion wave damping via the Langmuir decay instability.

1. Introduction

Proposed targets for achieving ignition on the NIF laser will be of unprecedented size and electron temperatures. Prediction of NIF stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) [1] instability levels relies on understanding the dependence of instability growth on plasma parameters and the conditions under which the instabilitites saturate. New tools have been developed which have increased our confidence in predicting and controlling instabilities in NIF plasma conditions. For example, Thomson scattering [2] on Nova has led to detailed measurements of the plasma waves associated with SBS and SRS and a parallel version of the nonlinear hydrodynamic code F3D [3,4] can now model Nova-sized problems.

Our studies are organized into two categories. First, a number of Nova experiments were conducted to identify the saturation mechanism for SRS, and to measure the saturated fluctuation level of the SBS ion wave. In addition, cryogenic targets were used to examine the dependence of instability levels on ion wave damping. Second, beam smoothing techniques have been investigated. Possible NIF beam smoothing techniques include kinoform phase plates (KPP's), polarization smoothing [5,6], and smoothing by spectral dispersion (SSD) [7]. An important component of this study is the development of a parallel form of F3D, pF3D, which is capable of modeling millimeter-sized plasmas, therefore making it easier to take into account plasma effects on the laser propagation through the target plasma. The remainder of the text will discuss these recent results in more detail.

2. SBS and SRS saturation experiments

The Langmuir Decay Instability (LDI) has tentatively been identified in the Nova gasbag experments. LDI is the decay of the SRS electron plasma wave into another electron plasma wave and an ion acoustic wave. LDI is identified by Thomson scattering [2] off the ion acoustic wave. Figure 1a shows the geometry of the experiment, in which the 4ω Thomson scattering probe beam [8] and the SRS driving beam geometry are chosen to satisfy the k-matching condition with the LDI ion wave. The target plasma is a gasbag filled with 49.5% CH_4, 49.5% C_3H_8, and 1% Ar, which is heated using 9 of the Nova beams; this gives a density of $0.11n_c$ (where n_c is the critical density) for 0.53 μm, the wavelength of the SRS-driving beam (beamline 9) which has an intensity of 6×10^{14} W/cm^2. Figures 1b and 1c compare Thomson scattering streak records with and without the SRS-driving beam and show the appearance of the LDI signal after the heater beams have turned off. Measurements of the SRS reflected light levels show saturation, consistent with the LDI saturation mechanism. This result is important for identifying the physical process to be modeled in F3D.

Thomson scattering measurements were also made on Nova gasbag experiments to quantify the fluctuation level of the SBS ion wave. In these experiments, nine of the Nova beams were used to form the plasma and the tenth was used to drive SBS. The geometry between the SBS-driving beam and the 4ω Thomson scattering beam was such that collective scattering from the SBS ion wave was obtained by the Thomson scattering detection system. Scattered signal from thermal plasma fluctuations was also collected after the driving beam turned off, allowing a quantitative measurement of the growth of the ion fluctuations as a result of the SBS instability. This was obtained for several different laser intensities (see Fig. 2) so one can observe the onset of SBS saturation for laser intensities above 2×10^{14} W/cm^2. This result is important because, from the known plasma conditions and the width of the Thomson scattering ion wave feature, one has the opportunity to identify the saturation mechanism (analysis is underway). The measured fluctuation levels are also an important benchmark to test the physics modeled by F3D.

Cryogenic He/H_2 gasbags were chosen to study the effect of ion damping on SRS levels. Experiments were performed to find the mixture which minimized the scattered light levels and to investigate the importance of ion wave damping [9,10]. Three gas mixtures (He/Ne, H_2/He, H_2/He/Ne) were used to vary the ion damping from ~0.1 to ~0.4. Preliminary analysis of the results show that there is not a strong dependence of SRS reflectivity on ion damping, but that the SRS levels (< 10%) remain tolerable. SBS is seen to decrease with increasing damping (see Fig. 3)

3. Modeling developments

The parallel code pF3D is being developed to predict the backscatter, transmission, spreading and deflection of NIF laser beams in ignition targets. Presently, pF3D contains physics modules which model light propagation, nonlinear 3D Eulerian hydrodynamics and linearized nonlocal heat conduction which means that presently the simulations include filamentation, beam bending and forward SBS. Present computational capabilities allow the simulation of a plasma with the dimensions 225 μm x 900 μm x 2500 μm, which is approaching the size of a NIF beam. Preliminary simulations indicate that plasma self-smoothing of the beam is an important effect which needs to be modeled in order to better design laser smoothing concepts such as KPP's.

SBS backscatter from scale 1 hohlraums on Nova has been measured for a range of laser intensities and for SSD with a range of bandwidths [6]. By postprocessing LASNEX simulation of the experiment with LIP and PIRANAH, the calculated spectral history has been shown to be in agreement with the data, with most of the SBS occuring near the hohlraum wall. F3D simulations showed that the nonlinearities in the acoustic wave evolution are important for understanding the intensity dependence of the SBS evolution (see Fig. 4). Most of the SBS occurs in hotspots with $I > 3I_0$, where I_0 is the average intensity. Simulations using pF3D showed that the onset of plasma self-smoothing in the range $2 – 4 \times 10^{15}$ W/cm^2 is important for understanding the intensity scaling of SBS.

4. Summary

Recent results have increased our understanding of SBS and SRS saturation mechanisms under conditions similar to those expected in NIF ignition targets. Powerful computation models are being developed which will allow the modeling of an entire NIF beam in a realistic plasma. Future work will be directed towards designing the beam smoothing requirements for NIF ignition targets.

5. Acknowledgements

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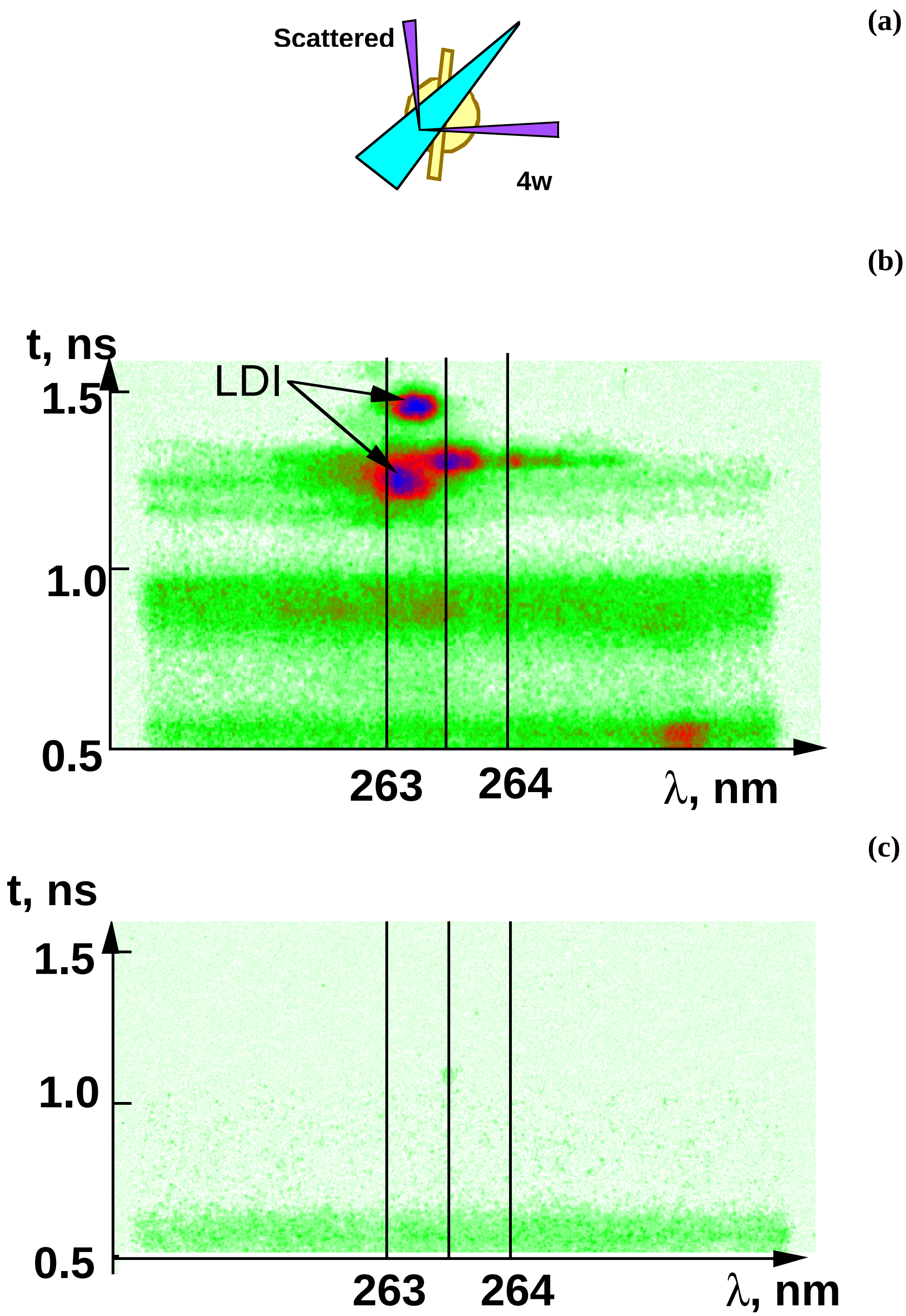


Figure 1. Results of Thomson scattering measurements of the LDI ion wave product from the decay of SRS electron plasma waves. (a) The probe and collection geometry. (b) Thomson scattering signals observed with a pump beam. (c) Measurements without a pump beam.

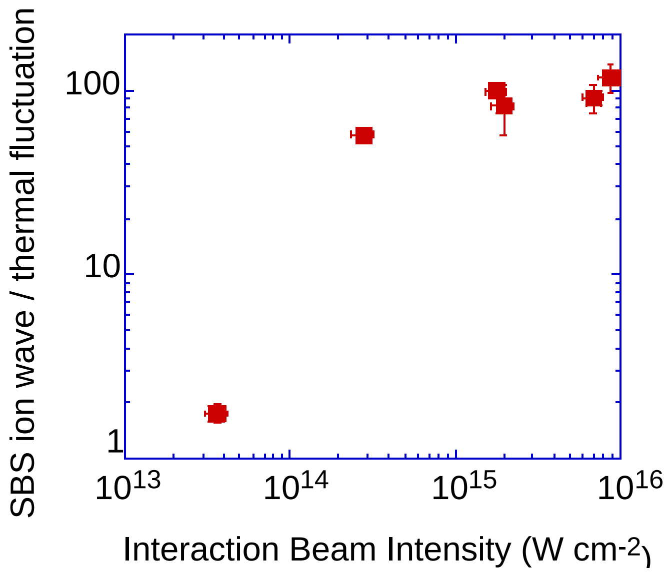


Figure 2. Measured SBS ion wave density fluctuations versus incident laser intensity. The fluctuation level is measured using Thomson scattering.

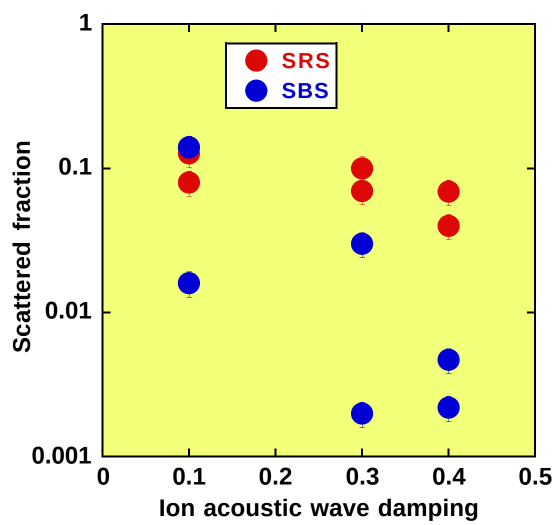
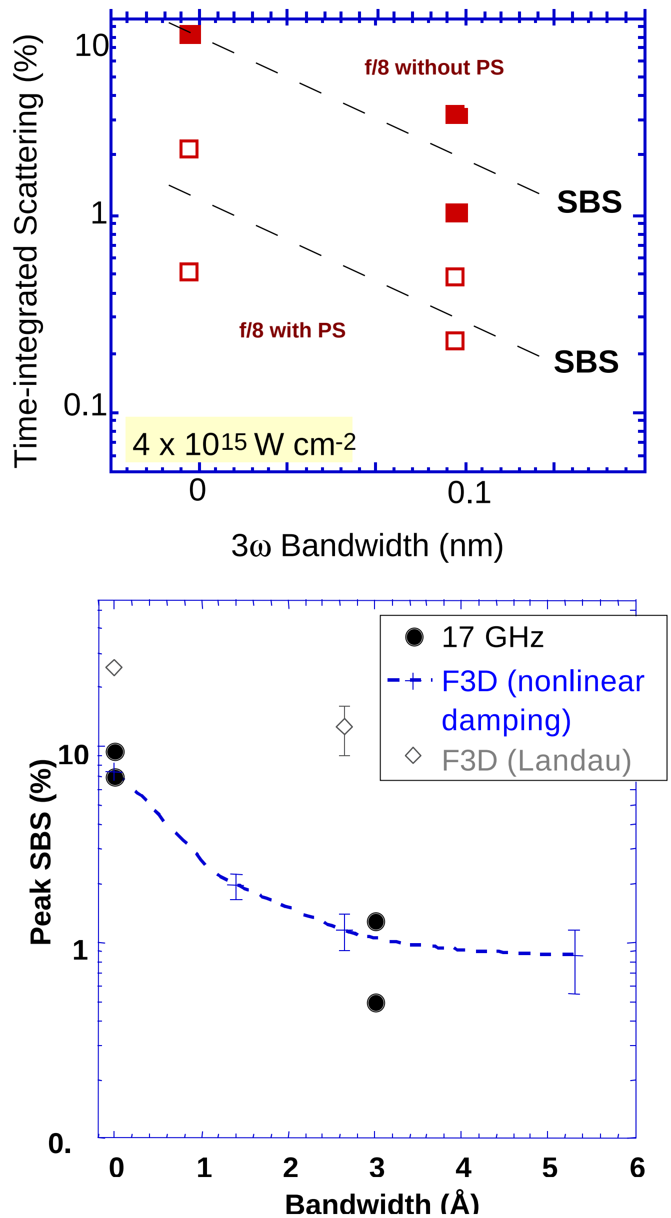


Figure 3. Backscattered SBS and SRS levels as a function of ion wave damping from cryogenic gasbag targets.



(a)

(b)

Figure 4. Results for polarization smoothing in scale 1 hohlraums using an f/8 focusing geomtery: (a) experiments, and (b) comparisons to F3D results.